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Where to Go for ESD Information

Information on procedures for controlling ESD is readily available.

Q. Where can I find information on electrostatic discharge (ESD)? What is it and how is it created?

A. Perhaps a good starting point is the six-part series on "ESD Basics" that appeared in *Compliance Engineering* in 1998. Prepared by the ESD Association (Rome, NY), the series covers the following topics: An Introduction to ESD; Principles of ESD Control; An Overview of ESD Control Procedures and Materials Auditing and Training; Device Sensitivity and Testing; and ESD Standards. The series is posted on the ESD Association's Web site, <http://www.esda.org>.

The ESD Association is a focal point for information on ESD. The association sponsors the annual EOS/ESD Symposium, which features technical papers, tutorials, workshops, and exhibits over a five-day period. The 2001 Symposium is scheduled September 9-13 in Portland, OR.

The ESD Association or local chapters sponsor a number of regional educational programs. During 2001, ESD tutorial programs are slated in Arizona, California, Illinois, Texas, and Oregon, with topics ranging from ESD basics to the new ANSI/ESD 20.20 ESD Control Program Standard.

Other educational resources available from the association include textbooks such as *ESD Program Management* by Theodore Dangelmayr or *ESD in Silicon Integrated Circuits* by Ajith Amrasekera and Charvaka Duvvury, technical reports on subjects such as "Can Static Electricity Be Measured?" and

proceedings from past EOS/ESD symposia. The association's *ESD Handbook* is currently being updated and revised to support the ANSI/ESD 20.20 ESD Control Program Standard. The handbook discusses ESD, as well as procedures and processes for controlling ESD.

For details on ESD Association programs and the location of various local ESD organizations, check the ESD Association Web site, <http://www.esda.org>, or contact the ESD Association at 7900 Turin Rd., Bldg. 3, Rome, NY 13440; tel: 315/339-6937, fax: 315/339-6793, e-mail: eosesd@aol.com.

Other Educational Resources

Some suppliers of ESD products and services also sponsor educational seminars. Several trade publications, such as *Compliance Engineering*, regularly run articles on electrostatic discharge. Electronics-related trade shows often include seminars and technical sessions on ESD. Check the calendars of the various publications for these events and activities.

Another source of books and publications on electrostatics and ESD is *Electrostatic Applications*, tel: 408/779-7774, fax: 408/779-3638, e-mail: electro@electrostatic.com, Web site: <http://www.electrostatic.com>.

To submit your questions to the ESD Help Desk or to browse the archives of past questions and answers, go on-line at <http://www.ce-mag/esdhelp.html>. Information on the ESD Association may be found at <http://www.esda.org>. ■

assemblies, has merged its operations with Datacom-Textron, a manufacturer of test equipment for copper-based local-area networks. Datacom's operations will move to RIFOCS's Camarillo, CA, facility.

- **CTS Corp.** (Elkhart, IN), a manufacturer of electronic components and assemblies, has been selected by Lucent Technologies Microelectronics Group (Allentown, PA), a specialist in semiconductors for communications applications, to supply multilayer, low-temperature, cofired ceramic substrates for Lucent's integrated Bluetooth radio subsystem.
- **RF Monolithics Inc.** (Dallas), a developer and manufacturer of radio-frequency components, has signed manufacturing agreements with Automated Technology Inc. (Cabuyao, Philippines) and Cirtek Electronics Corp. (Binan, Philippines).

- **ETL Semko's** Montreal office has been awarded full acceptance as a national certification body, authorized to grant internationally recognized conformity certificates to electrical-product manufacturers by the International Electrotechnical Committee System for Conformity Testing to Standards for Safety of Electrical Equipment (IECEE).

- **Schaffner EMC Inc.** (Edison, NJ), a supplier of EMI components, EMC instrumentation, and test systems, has signed an agreement enabling Pioneer-Standard Electronics Inc. (Cleveland), an international distributor of electronic components and computer systems, to distribute Schaffner EMI filter products.

- **Ansoft** has announced the opening of two training centers, one at the Beijing Institute of Technology and one at Xidian University (Xi'an, People's Republic of China), as well as a support office in Shanghai.

Corrections

In regard to the Newsline story "FCC Clarifies Equipment Authorization for Class B Computers and Peripherals," which appeared in *CE's* November/December issue, FCC will no longer accept applications for certification under 47 CFR 2 for any Class B PC or PC peripheral that can be approved by declaration of conformity (DoC). However, certification by DoC is still an option, in addition to certification by a telecommunications certification body.

Internet Address

The editor's page in the November/December issue contained an incorrect internet address for obtaining an IEE guidance document in PDF format. To retrieve the document, please visit <http://www.iee.org.uk/PAB/EMC/core.htm>. ■

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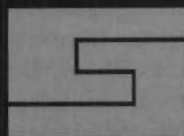
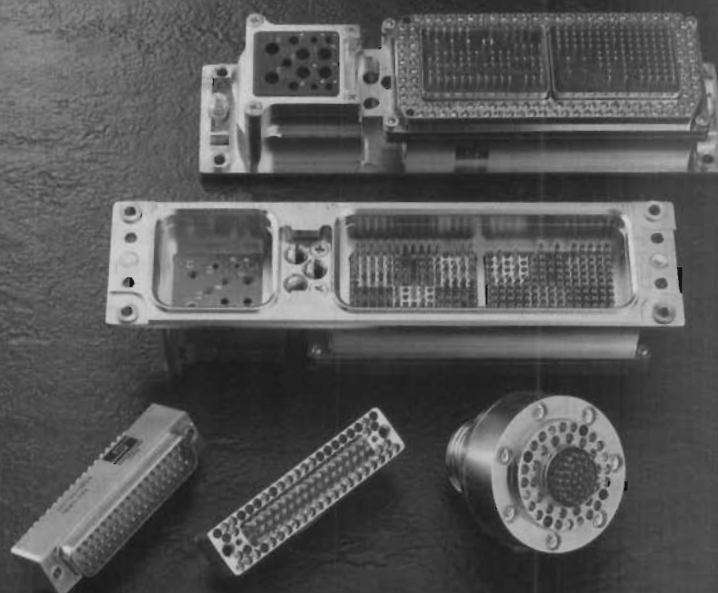
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Niels Jonassen

How Is Static Electricity Generated?

Predicting the level of static build-up is rarely possible.

Nearly all static-electric phenomena are caused by the interaction between charges located on the surfaces of bodies which might be conductive as well as insulative. A basic question, therefore, is, how do the bodies obtain the charges? The purpose of this column is to present a qualitative overview of the physical processes involved in static build up. The title might seem to imply a discussion on developing formulas for quantitatively predicting the magnitude of electrification from material parameters and other physical conditions. Quantitative predictions, however, are rarely possible.

It is important to first stress that charges are never generated. They always exist in atoms—as positive charges on the protons of the nuclei, and as negative charges on the electrons around the nuclei. An electric effect can be seen only when electrons are removed from some of the atoms in one material and transferred to atoms in another (or maybe even the same) material. The electric effect is caused by the attraction between opposite charges and the repulsion between like charges.

We are normally only aware of this effect if the electron-exchanging materials are separated in such a manner that at least part of the charges do not reunite



Niels Jonassen

during the separation process. The transfer of electrons between atoms or molecules might occur when two solids—identical or different—contact each other, with electrons crossing the interface in a

preferential direction, giving one material a positive and the other a negative excess charge.

The exchange of electrons could also

occur when an insulative liquid flows through a tube, when a liquid of almost any type breaks up into droplets of nonuniform magnitude, or when droplets fall through an inhomogeneous field, such as in a thundercloud.

The number of electrons transferred in any charging process is enormous. Here are some examples. If a powder, such as sugar or flour, slides down a tube and sticks to the wall, the charge on each tiny particle could be 10^{-14} to 10^{-13} C, i.e., 100,000 to 1 million electrons have been transferred per particle. A person who has walked across a carpeted floor receives a shock when touching a door-knob that typically has a charge of about 10^{-7} C. Powder sliding down a tube often has a specific charge of about 10^{-7} C·kg⁻¹. A plastic folder rubbed with a piece of cloth or fur typically produces a charge of 10^{-7} C per sheet.

Charging of Solids: Triboelectrification

The most important type of charge separation involves the contact and friction between solids known as triboelectrification. When two solid materials, A and B (see Figure 1), contact and possibly rub against each other, electrons could move across the interface.

Metals. It may be surprising that triboelectrification also happens when the two contacting materials are metals. And even more surprising is that this friction

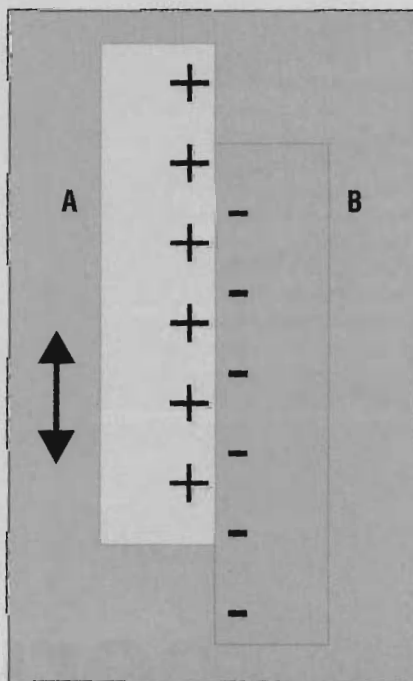


Figure 1. Triboelectrification.

between metals is the only case in which the result of the charge transfer can be accurately predicted. When two metals contact, a voltage difference is established across the interface—the so-called contact potential difference—with a magnitude from a couple of tenths to a few volts.

If the metals are “well-defined” metals, the contact potential difference can be calculated from the work functions, i.e., the energy it takes to remove a loosely bound electron from the metal. It should be stressed, however, that this charge exchange between metals only gives rise to what we normally understand as static electricity when the two metals are separated extremely quickly, such as when a metal powder is blown against a metal surface.

Insulators. It is likely that processes similar to those described for metals could take place during contact between materials of which one or both are insulators. It is, however, difficult to characterize completely an insulating surface. For many materials, especially noncrystalline ones, the energy levels are badly defined and, therefore, the detailed contact processes are not known.

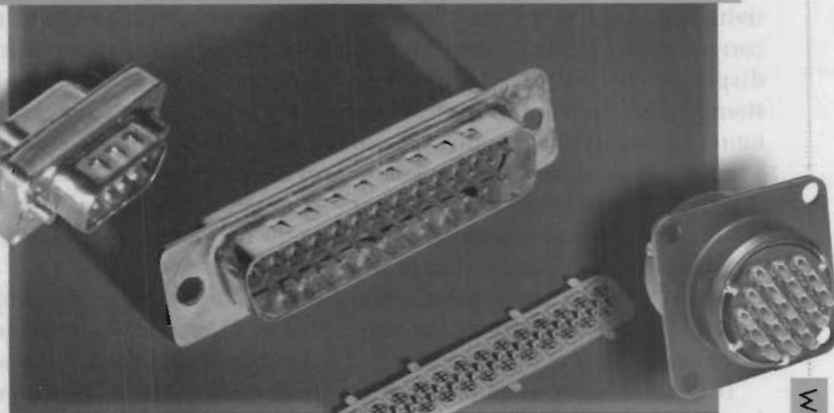
It is conceivable that only electrons located close to the surface can participate in the charging of highly insulative materials. Similar to metals, for some of these materials it is possible to measure the work function for loosely bound electrons. Because the measured values only hold true for materials with well-defined surface states, the practical implication of this is small.

As soon as a surface prepared in vacuum is exposed to ordinary air, the state—including the energy levels of surface electrons—can change considerably. Consequently, charging experiments with insulators can only yield quantitatively predictable results if the surfaces are carefully prepared and the experiments are performed in vacuum. And such experiments might disclose very little about what one could expect to find under more-practical conditions.

Contact Electrification: Triboelectric Series

One of the material parameters influencing the course of a charging process between two solid materials is the per-

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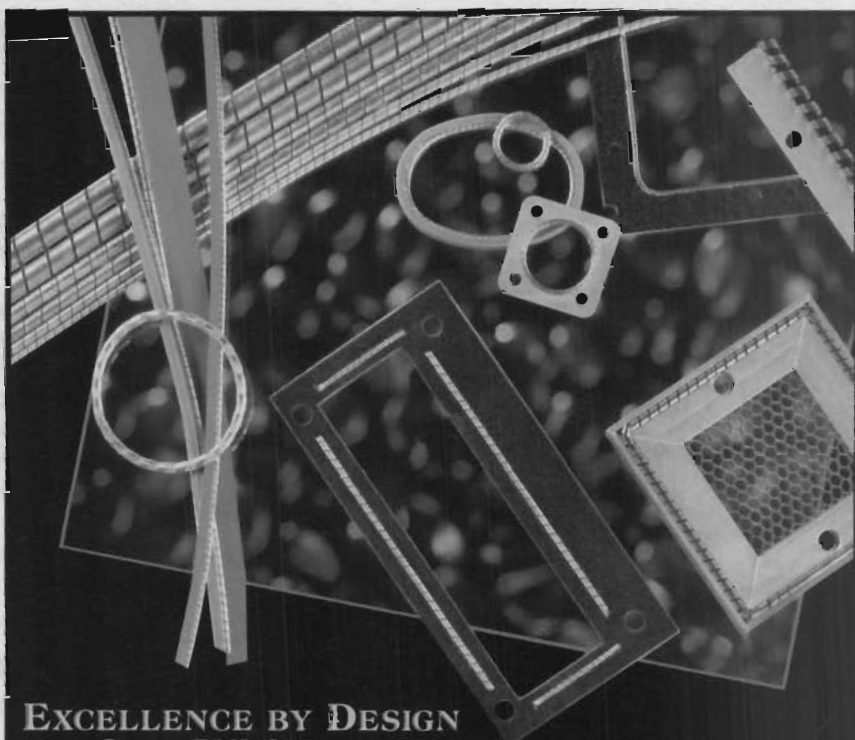


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Mr. Static

mittivity. Scientifically speaking, permittivity is defined as the ratio between corresponding values of the dielectric displacement and the electric field strength. However, in this context, it is more important that permittivity is also a measure of the ability of the material to become polarized.¹ If an ion or another small, charged atomic or molecular cluster lands on an insulative surface, it will be bound to the surface by polarization forces. The stronger the forces, the higher the permittivity of the material.

This is the background for Coehn's law, which states that when two materials are in contact with each other, the one with the highest permittivity becomes positive. This law was originally based on a comparison of known values of permittivity and published triboelectric series (i.e., a list of materials arranged in such an order that any material will become positively charged when rubbed against another material that is nearer the negative end of the series). There is no doubt that such a correla-

tion exists, but with quite a few exemptions. And certain groups of materials can even be arranged in a closed series.

Table I shows an example of a triboelectric series. Such a series should be used with caution because the order of the materials could vary from series to series. Some series even locate air at the top of the positive end, which is a mistake.

From the relative position of a material in a series, it is possible to predict the sharing of polarity. However, the magnitude of the charges separated by contact and friction between two given materials can only be predicted with a high degree of uncertainty.

The magnitude of the charges often increases with the degree of friction between the surfaces, and the reason for this could be that the rubbing increases the area of contact between the surfaces while the charging process itself is only governed by the energy state of the surfaces, and that charged particles cross the interface at points of sufficient proximi-

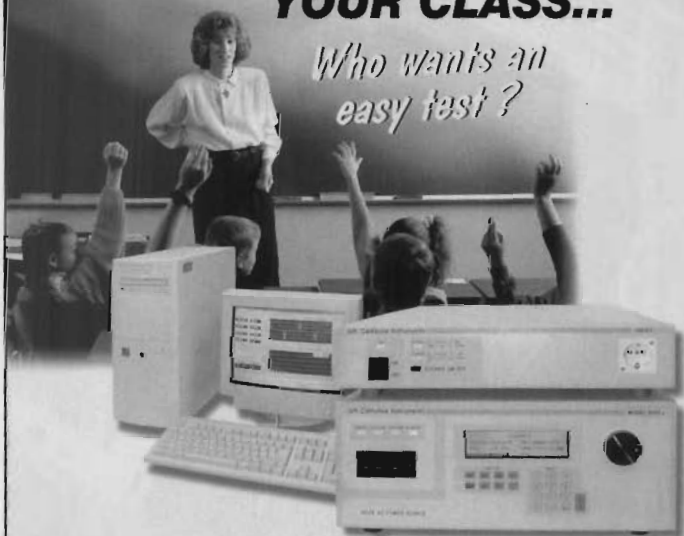
ty. This, however, is hardly a satisfactory interpretation, because then it wouldn't be possible to explain the fact that two identical surfaces can get charged by rubbing against each other. It could be argued, though, that no two surfaces are ever identical, and that incidental and uncontrollable differences might cause different affinities to charged particles.

Asymmetric Friction

As mentioned earlier, the degree of friction between two materials influences the contact area, and thus the exchange of charges. But the process of friction could have a specific influence of its own. It can be demonstrated that if two identical surfaces—macroscopically speaking—are rubbed against each other in such a way that the contact takes place between a small area of one surface and a larger area of the other, the polarities of the surfaces are likely to change if the roles of the surfaces are interchanged. Figure 2 illustrates this process. Two pieces—A and B—of the same material are rubbed against

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each other. In Figure 2a, A is stationary and B is being used as the bow on a string. If the bow, B, becomes positive, then, when the roles of A and B are reversed, the bow (in this case A) will again be positive, as seen in Figure 2b. This is asymmetrical friction.

A possible explanation of this phenomenon is that the asymmetry could cause a thermal gradient to develop between the surfaces, thereby inducing already existing charge carriers to move in a certain direction. It is also possible that the charge carriers are produced by a thermal dissociation of the material into charged components.

Other conditions, such as the existence of external electric fields across interfaces, may also play a role in charge ex-

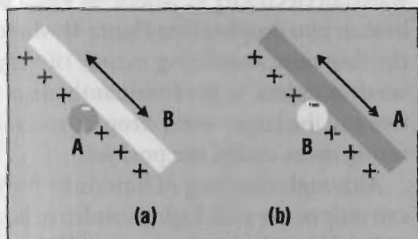


Figure 2. Asymmetrical friction.

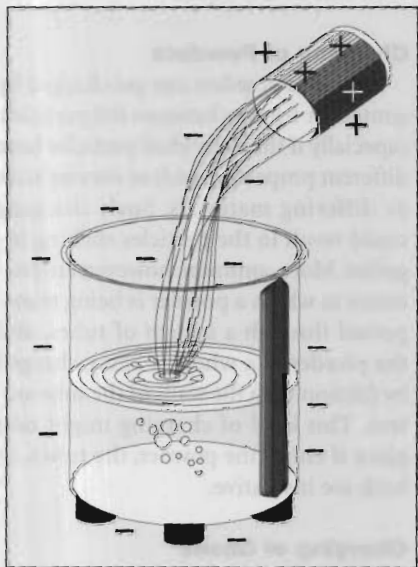


Figure 3. Electrification by flow of liquid.

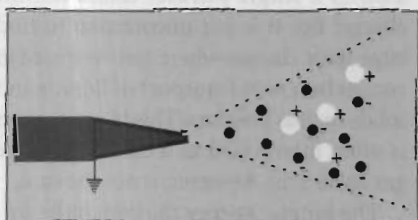


Figure 4. Electrification by spraying of liquid.

Positive end
Plexiglass
Bakelite
Cellulose nitrate
Glass
Quartz
Nylon
Wool
Silk
Cotton
Paper
Amber
Resins (natural and man-made)
Metals
Rubber
Acetate rayon
Dacron
Orlon
Polystyrene
Teflon
Cellulose nitrate
Polyvinyl chloride
Negative end

Table 1. An example of a triboelectric series.

change between contacting solid materials. This effect can be used in an electrostatic separation process.

Postcontact Processes. Although contact between metals might produce charge transfer, no net charge will remain on the metals after separation unless at least one of the metals is insulated and the separation happens very quickly. If, on the other hand, at least one of the materials is an insulator, both surfaces will be charged immediately after separation. If they are both insulative or if one is an insulated conductor, the charges might remain on the materials even when they are far removed from each other.

During the initial separation, a series of processes could take place that would reduce the magnitude of the charges remaining on the surfaces. Such processes include decay and various types of discharges, ranging from corona discharge to regular sparks.

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Mr. Static

Charging of Liquids

The charging of solid materials by contact and friction is the best known type of static electrification, but it is not the only one. Liquids can also get charged, by flowing through tubes or by spraying, for example. However, the mechanism involved in the charging of liquids is somewhat different from the processes active in solids charging.

It has been demonstrated that phe-

nomena like electrophoresis and capillary electricity in aqueous solutions can be explained if it is assumed that, on the interface between a liquid and a solid, or between a liquid and a gas, an electrical double layer exists in the liquid with a layer of charge close to the surface and a layer of the opposite polarity a short distance into the liquid.

Flow and Spraying. If the surface of a liquid is changed, the electric double layer

has to be formed or destroyed. These processes are supposed to have a certain inertia, which implies that it is possible to separate the charges of the double layer by mechanical action on the liquid.

If a liquid is flowing through a tube, there is a tendency for the outer charge of the double layer to be given off to the tube and the inner charge to be carried along with the flow (see Figure 3). The effect of the charging increases with the resistivity of the fluid (and depends on several other parameters). Consequently, only highly insulative liquids ($\rho > \text{ca. } 10^7 \Omega \cdot \text{m}$) will show charging by flow. Water, therefore, will not charge by flow.

It is well known that the breaking up of a liquid into droplets could cause charge separation. This is what happens with waterfall electricity or whenever water is broken into droplets (see Figure 4) where the fine mist, consisting mainly of very small droplets, is predominantly negative and the larger water drops, precipitating more easily, are positive.

Although charging of liquids by flow can only occur with highly insulative liquids, charging by spraying can happen with almost any liquid.

Charging of Powders

Dust and powders can get charged by contact or friction between the particles, especially if the individual particles have different properties, such as varying sizes or differing materials. Such charging could result in the particles sticking together. More common, however, are processes in which a powder is being transported through a system of tubes, and the powder as a whole is being charged by friction with the walls of the tube system. This kind of charging might take place if either the powder, the tubes, or both are insulative.

Charging of Gases

This section could actually be abbreviated to a single phrase: Gases do not charge! But it is not uncommon to find large static charges where gases are used in connection with transport of liquids and solids such as powders. This phenomenon is often interpreted as a charging of the gas itself. This, however, is not the case.

The kinetic energy that might be imparted to a gas molecule in an airflow—even at high velocities—is much lower

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than the thermal kinetic energies at normal temperatures. It is also much lower than the level required to knock an electron off either the gas molecule itself or the container walls, for instance.

This theoretical prediction is backed by experiments in which filtered air is blown against a solid surface. No charging occurs. The charging observed with ordinary compressed air is caused by liquid or solid impurities of the gas impinging on the target and, therefore, is a case of dust charging rather than gas charging. The polarity of the target charge can be either positive or negative, depending on the nature of the target as well as that of the impurities.

Placing air at the top of a triboelectric list, therefore, makes no sense. Nearly all charging experiments I have done with nonfiltered air impinging on a variety of solid materials have shown a positive charge on the target, which apparently should place air at the negative end of the list. But that, too, is wrong. All experiments

with carefully filtered air show no charging, demonstrating that gases do not charge.

Conclusion

It is very rarely possible to accurately predict the level of static buildup one might encounter under certain, even well-defined, working conditions, but there are exceptions. If one is dealing with liquids flowing through tube systems and the resistivities, resistances, capacitances, flow rates, and system geometry are known, then it is certainly possible to calculate fairly accurately the charging currents and equilibrium voltages.

But if one is dealing with the conditions in the electronic industry, little is usually known about the charging conditions. Materials with often-unknown properties are rubbing against each other and exchanging charges at an unknown and unpredictable rate. Sometimes one can measure the end result, but here one should be aware that the measurement itself could interfere essentially with the

quantity to be measured.

So we're left with the question: What can we do? Can we do something to prevent charging? The short answer: very little. Can we do something to abate the effects of the charging? The answer: a lot. Abating the effects will be addressed in a future column.

Reference

1. Niels Jonassen, "Polarization, for Better or Worse," in *Mr. Static, Compliance Engineering* 17, no. 5 (2000): 34-40.

Niels Jonassen, MSc, DSc, worked for 40 years at the Technical University of Denmark, where he conducted classes in electromagnetism, static and atmospheric electricity, airborne radioactivity, and indoor climate. He is now officially retired and divides his time among the laboratory, his home, and Thailand, writing on static electricity topics and pursuing cooking classes. He can be reached at mr.static@scientist.com. ■

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On Your Mark: A Primer on Symbols

Geoffrey Peckham

On Graphical Symbols

Understanding how and when to use internationally accepted symbols such as the lightning bolt is an important part of product design.

Graphical symbols have become an integral part of the world in which we live. Some of the first written languages were essentially made up of symbols that conveyed a word, a group of words, or an entire concept. It is interesting to note that in some parts of the world languages evolved as alphabets comprising individual characters whereas in other areas, such as the Far



Geoffrey Peckham

committees have identified four types of symbols: technical documentation symbols (architectural, electrical diagram), public information symbols (rest room, luggage), safety symbols (electrical hazard, radiation), and function and control symbols (windshield wipers, earth ground).

This column is designed to help manufacturers understand the process and progress of symbol standardization. Information on specific standardized symbols is provided to illustrate how and when to use them and ensure that they conform to appropriate standards. Each column will highlight at least one safety or function and control symbol. The definition for each symbol will be given as well as examples of its proper use.

Electrical Hazard

The lightning bolt shown in Figure 1 is symbol No. 5036 in IEC 60417, "Graphical Symbols for Use on Equipment." Although many shapes have been used for a lightning bolt over the years, this is the official illustration accepted by IEC. Note that this bolt

has no divots out of the top, a relatively solid arrowhead, a thin inner middle line, and the precise angles shown. Any lightning bolt used other than this one does not conform to the standard. IEC defines this symbol as: "*Dangerous voltage*—To indicate hazards arising from dangerous voltages. Note—In case of application in a warning sign, the rules according to ISO 3864 shall be adhered to." Figure 2 illustrates how this symbol is used when it is part of a graphic-only safety sign or label as defined by ISO 3864, "Safety Colors, Safety Signs." In Figure 3, the lightning bolt is integrated into a safety sign or label in compliance with U.S. ANSI Z535.4.

The next installment of this column will focus on function and control symbols, and several ground symbols will be described and illustrated.

Geoffrey Peckham is president of Hazard Communication Systems (Milford, PA), a company specializing in the design and production of product safety labels. For more information, visit <http://www.hazcomsys.com>. Peckham is chairman of the U.S. technical advisory group to ISO/TC 145 on graphical symbols. He can be reached at gpeckham@hazcomsys.com. ■



Figure 1. IEC Symbol 5036.



Figure 2. ISO 3864, electrical hazard.

East, concepts evolved into more self-contained, abstract characters. As the marketplace for goods and services has become more fluid, however, multiple languages in a global market means that we now need to develop a common symbolic language to convey critical information across language barriers.

To address this need, the standardization of symbols by the International Organization for Standardization (ISO) and the International Electrotechnical Commission (IEC) is now in full swing. The two technical committees responsible for most of this standards activity are ISO/TC 145 and IEC SC 3C. The

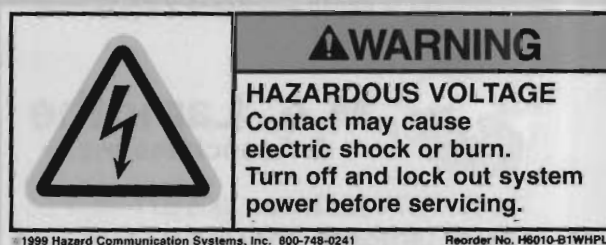


Figure 3. An electrical hazard safety label in compliance with ANSI Z535.4.